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PERMEABILITY OF STONE

BY

D. W. KESSLER, Research Associate
Bureau of Standards

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By D. W. Kessler

ABSTRACT

The permeability of natural and artificial stone has been little studied in the laboratory. Actual determinations of this property have been confined mainly to concrete. The various means employed for this purpose have not been free from criticism. This paper describes an apparatus which operates on somewhat different principles than those heretofore employed and permits the use of a considerable range in pressures. Since the permeability of the very dense materials is small, it is desirable to use high pressures in experiments on such. With this object in view, some attention has been given to determining the variation of the permeability of certain materials with the pressure. Since measurements of this property have to be confined to relatively thin specimens it is of prime importance to find out how the results of such tests apply to greater thicknesses of the material. A limited number of tests have been made on a certain material by varying the thickness of specimens. Six types of natural stone have been tested for comparative data and to determine the adaptability of the apparatus to a considerable range in textures.

CONTENTS

I. INTRODUCTION

The permeability of a solid may be defined as that property which permits any substance to penetrate or pass through it. In order to compare the permeability of one porous material with that of another, one may resort to measurements of the flow of some convenient fluid through each under similar conditions. The permeability of stone and similar building materials is usually conceived to be the rate at which water will flow through. To accurately define this property one may consider it as being the amount of water which will flow

Permeability, defined p.155, is elsewhere used inter-changeably with flow rate.

through a unit area of unit thickness in unit time under unit-pressure difference between the two faces of the specimen. Due to the fact that little work has been done to determine this property for stone and that its accurate measurement is beset with several difficulties, no attempt has been made in this study to establish a standard unit of measurement. In order to establish a convenient unit that would be applicable to a class of materials of such variable characteristics it would be necessary to conduct an extended series of preliminary experiments to determine the limiting values and eliminate some of the uncertainties of the test. The data derived from the tests described herein were obtained under various conditions for the purpose of gaining some general information on this property.

The main purpose of this paper is to describe an apparatus which has been developed at the Bureau of Standards during the past year for determining the water permeability of natural stone at various pressures. Several tests have been made on various types of stone in order to determine the adaptability of the apparatus to different materials. Since very little information is available on the permeability of stone, the determinations given herein may prove of interest and serve to convey some idea of the variation of this property from one type of stone to another.

Since the apparatus itself was an experiment, many of the parts were adapted from stock materials in order to reduce the cost of construction. Other laboratories have shown a desire to duplicate this apparatus, hence a complete set of plans and description is included in this paper as well as a detailed account of its manipulation. As a permanent piece of laboratory equipment, certain improvements could be made at a slight increase in cost which would simplify the operation and give a more compact apparatus.

The writer wishes to express his appreciation to Dr. A. F. Melcher, formerly of the United States Geological Survey, for valuable suggestions concerning the design of the specimen holder.

II. DESCRIPTION OF APPARATUS

Since this apparatus may be found useful in the study of other structural materials and various problems connected therewith, a rather detailed description of its construction and operation will be given.

The apparatus is illustrated in the following figures: Figure 1 is a photograph of the complete assembly; Figure 2 shows the plan, front, and end views with the essential parts labeled; Figure 3 shows a vertical cross section through the center of the specimen holder and certain details of the accumulator; Figure 4 shows the assembly of specimen container, a sample of the asphalt for calking, three

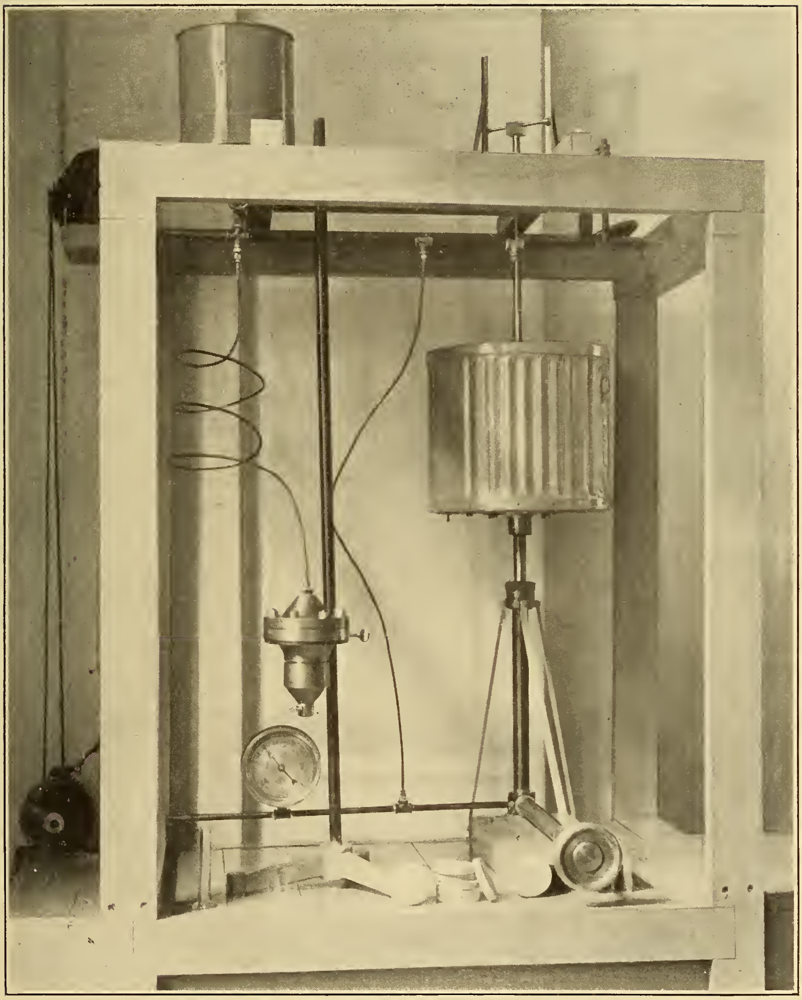
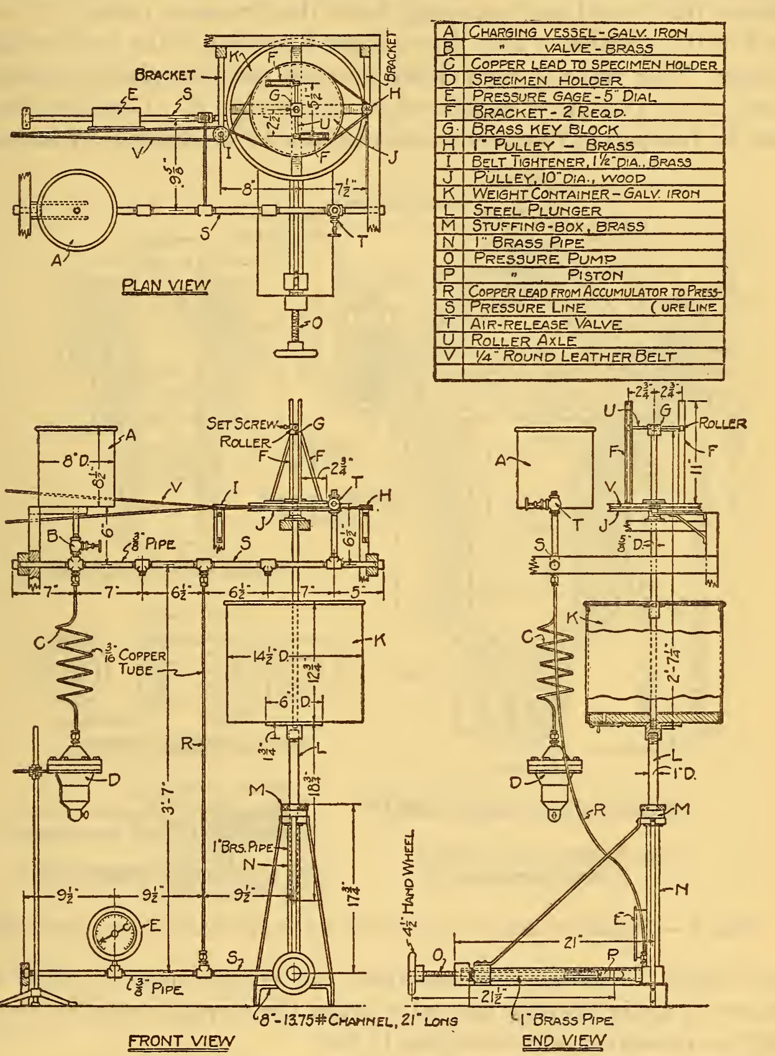


FIG. 1.—*Photograph of permeability apparatus in operation*

specimens broken under water pressure, and a collection of stone specimens ready for testing.

The apparatus consists mainly of a heavy brass specimen holder (*D*, fig. 2) and an accumulator for producing and maintaining the



A	Charging vessel-galv. iron
B	" valve - brass
C	Copper lead to specimen holder
D	Specimen holder
E	Pressure gage - 5" dial
F	Bracket - 2 reqd.
G	Brass key block
H	1" Pulley - brass
I	Belt tightener, 1½" dia., brass
J	Pulley, 10" dia., wood
K	Weight container - galv. iron
L	Steel plunger
M	Stuffing-box, brass
N	1" Brass pipe
O	Pressure pump
P	" piston
R	Copper lead from accumulator to pressure line
S	Pressure line
T	Air-release valve
U	Roller axle
V	1/4" Round leather belt

FIG. 2.—*Plan, front and end views of apparatus with essential parts designated*

desired water pressure. The specimen holder is made in three parts, namely, the central part with a circular recess in which the specimen is placed, a cover plate which is clamped firmly to the central part, and a cup-shaped vessel having a sharp-edged top of known diameter which can be screwed into the lower portion until the edge comes in contact with the specimen.

The accumulator is connected to the specimen holder through a pressure line, *S* (see fig. 2), by means of a strong, flexible copper tube. A water-storage vessel, *A*, is placed at a high point for charging the system. Charging is accomplished by opening the valve below this vessel and screwing back the pressure piston, *P*, to the end of its cylinder. This draws a good portion of the system full of water. The valve is then closed and the pressure piston screwed in until a few pounds is registered on the gauge, *E*. Considerable air will be trapped in the pipe which can now be discharged by means of

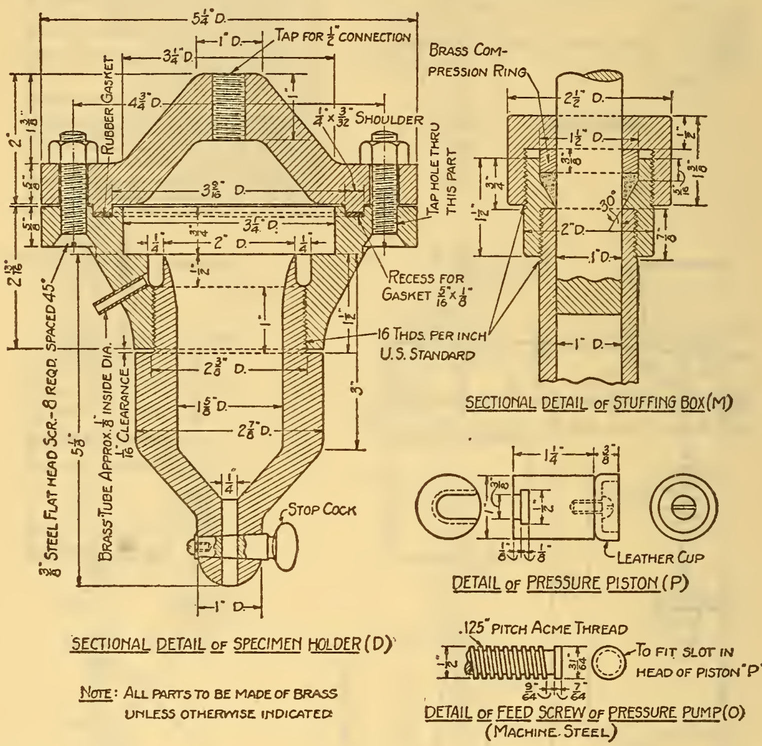


FIG. 3.—*Transverse sections of specimen holder and parts of the accumulator*

the valve, *T*. After this operation the system may be filled with water by again opening the valve below the storage vessel and screwing the pressure piston completely out.

Any desired pressure up to 300 lbs./in.² can now be obtained by placing the proper weight in the weight container, *K*. Shot is convenient for this purpose, and is easily distributed to prevent eccentric loading.

No attempt was made in constructing this apparatus to obtain a close-fitting plunger in the accumulator cylinder since this would have required expensive machine work. The plunger, which is a piece of cold-rolled steel, was turned and finished in the lathe to

Fig. 4.—*Assembly of the specimen holder with a specimen calked in place, a sample of asphalt used for calking, three specimens broken by the water pressure, and a collection of stone specimens ready for testing*

give a fairly snug fit. The water is held by means of a stuffing box, *M*, which is packed with cotten wicking well lubricated with tallow. This holds the water very effectively under the working pressures with no appreciable leakage. However, the friction on the plunger due to this packing is considerable, and in order to eliminate the variation in pressure due to this a means is provided for revolving the plunger while the test is in progress. This is accomplished by a small motor and speed reducer which turns the large pulley, *J*. This pulley revolves the weight container and plunger by means of the vertical shaft which is rigidly fastened to these. This vertical shaft was first grooved its entire length for a keyway, the key being made rigid with the pulley, *J*. However, it was found that the sliding friction on this key was so much that the pressures could not be regulated and another means had to be adopted. This trouble was overcome by mounting two brackets, *FF*, on the pulley to form runways for rollers on the roller axle, *U*, the latter being fastened to the top of the shaft by means of the key block, *G*. While there is still a small amount of friction due to this, it remains practically constant and hence can be compensated for by a definite weight in the weight container.

Another appreciable variation in pressure was found to occur if the belt was placed around the pulley in the usual way due to pulling this shaft to one side of the bearing. This was successfully overcome by placing a small pulley, *H*, on the opposite side to the speed reducer, as shown, to take the pull of the belt. A sliding pulley opposite this, used as a belt tightener, gives a further equalizing effect so that no appreciable variations were noted. In the operation of the apparatus it was found that the pressures can usually be depended upon to remain within 1 pound of that desired except when tests are being made on very porous materials. Under such conditions the plunger has to drop rapidly due to loss of water through the specimen and the pressure is apt to fall 3 or 4 pounds below that desired. However, this could probably be overcome by increasing the speed of rotation of the plunger. The speed used in these tests was 10 revolutions per minute.

III. PREPARATION OF SPECIMENS

The type of specimen used in this apparatus is a disk 3 inches in diameter which may be varied in thickness from three-quarter inch downward to as thin as desired. These are prepared by cutting a slab of stone of the required thickness and then cutting the disks from this by means of a 3-inch core drill. One face of the disk must be finished by grinding to a smooth, plane surface.

IV. PROCEDURE

In preparation for the test the specimen is placed with the smooth face downward in the recess of the specimen holder. The clearance of one-eighth inch between the edge of the specimen and the wall of the holder is then filled with hot asphalt. It is best to bring the level of the pitch one-eighth inch or more above the top of the specimen and when sufficiently cool press it against the wall of the holder, forming a cove, as shown in Figure 4. An asphalt which gave excellent results for this purpose was an 83° C. melting point oil-blown asphalt which is commonly used for roofing purposes. A lower melting point pitch was tried and found unsatisfactory in warm weather, as it would sometimes flow under the higher pressures and permit leakage. De Khotinsky cement was also tried with unfavorable results. It was found that the setting of the specimen could be done more satisfactorily by heating both it and the container on a hot plate for several minutes before pouring the bitumen.

When the specimen is calked in place and the pitch has cooled this part of the apparatus is supported on a strong ring stand and clamped to the cover plate. The system is charged with water as previously described and when a few pounds' pressure is brought upon the specimen the cup-shaped part is screwed into the bottom until it makes a firm contact with the specimen. When the full pressure is brought on the specimen the contact with the top of the cup will be made firmer due to the deflection of the disk.

Most of the materials experimented with were found to be permeable enough so that the water could be measured with sufficient accuracy in an ordinary graduate reading to 1 cc. Dense stones like granite, slate, and some others showed such a small percolation even at high pressures that more accurate measurements were necessary. In such cases a small vessel fitting snugly into the cup was filled with anhydrous calcium chloride to absorb the moisture as it came through. By weighing the desiccant before and after the test very small amounts of moisture could be measured.

In working on materials of rather coarse textures it was found that the contact obtained by simply screwing the cup-shaped part of the apparatus against the lower surface of the specimen was not satisfactory, since the larger pores and cavities in the stone would allow water to flow past the edge of the cup and cause the readings to be either too high or too low. This difficulty was overcome in the following manner: After the specimen was calked in place for the test a thin layer of graphite was rubbed on the sharp edge of the cup, which was then screwed into its position until it made contact with the specimen, then removed again. This marked a circle on the specimen which indicated where the contact was made.

A watch glass about one one-hundredth of an inch less in diameter than the top of the cup was then centered in the circle with the concave side next to the specimen. By means of a small bristle brush a narrow rim of hot paraffin was painted on the specimen around the edge of the glass. When cool, this was cut loose from the glass with the point of a knife. This formed a narrow band of paraffin which the sharp edge of the cup could be screwed into. The paraffin served to fill the pores of the stone and prevent the flow of water along the lower side of the specimen into or outside of the cup. This means may introduce a slight error in determining the area over which the flow is measured, but it is probably insignificant compared with the natural variation in the stone itself from one specimen to another.

The time interval for measuring the rate of flow was varied, depending on the rate at which water penetrated. In the more porous stones it was found necessary to take observations each minute, while with the dense materials the interval was increased to two hours or more. In the reduction of the data all values were computed for the flow in cubic inches per hour for 1 square foot of stone surface.

70660°—26†——2

TABLE 1.—*Results of permeability tests on stone*

[Specimens one-half inch thick except where otherwise stated]

Serial number	Material	Description	Remarks	Pressure in pounds per square inch: 1.2	25	50	75	100	125	150	175	200
				Permeability in cubic inches per square foot per hour								
1	Granite	Biotite granite		0.08		0.11		0.28		0.39		0.70
2	do	Dioritic granite		.06					0.08	.11		
3	Breccia	Volcanic breccia	Specimen ⅝ inch thick	.28								1.15
4	Slate	Green mica slate		.006		.08		.11				
5	do	Black mica slate		.008		.11						
6	Marble	White calcite	Parallel to bedding	.06				1.12			1.40	1.43
7	do	Veined calcite	do					.90				
8	do	Dolomite	Bedding not defined	.06		11.3		19.6		26.6		
9	do	do	Same as No. 8 (waterproofed)	.011						.08		
10	do	Coarse grained calcite	Bedding not defined	.35		16.8		28.0				31.4
11	do	do	Same as No. 10 (waterproofed)	.003		.11		.45				
12	Limestone	Dense, fine grained	Perpendicular to bedding	.42				.95				
13	do	Medium texture oolite	do	.36		4.2		16.2		29.0		39.2
14	do	Fine-grained dolomite	do			14.8		16.0				
15	do	Arenaceous dolomite	do	2.24				8.6				
16	do	do	Parallel to bedding	.90		44.8		109.0		151.0		
17	do	Medium texture oolite	Specimen ⅜ inch thick		504.0	980.0	1,370.0	1,760.0	2,350.0	2,860.0		
18	do	do	Specimen ¾ inch thick	19.5		622.0		1,285.0				
19	Sandstone	Dense, fine grained	Perpendicular to bedding	4.2	[1] 9.1	51.2	90.6	221.0	286.0	356.0	408.0	468.0
20	do	Medium texture	do	174.0	4,200.0							

[1] Measured at 30 lbs./in.²

V. RESULTS OF TESTS

Table 1 shows the results of permeability tests on six types of stone expressed in cubic inches per minute for 1 square foot of area. The specimens were one-half inch thick except as otherwise noted in the column under "Remarks." The low pressure of 1.2 lbs./in.^{2} was that due to the head of water above the specimen in the apparatus, while the other pressures were chosen to suit each particular case. Tests Nos. 17 and 19 were made at several pressures to determine the variation of permeability with the pressure, and 17 and 18 were made with a view of determining the variation with the thickness of specimen.

An adequate description of the materials in the table was not possible, so these notes, together with certain physical data of interest, have been placed in the following section. Since it is desirable to compare the permeability values with the results of absorption tests, the ratio of water absorption to permeability at 100 lbs./in.^{2} has been computed so far as the latter values are available and expressed as "ratio a/p." These data are included with the physical data in the following section.

VI. DESCRIPTION OF MATERIALS AND INDIVIDUAL TESTS

Due to the fact that all of the descriptive data concerning the materials tested could not be included in the table of results, this section is added to include the notes of general interest. The serial numbers used herein refer to the corresponding numbers in the first column of the table.

The pressures used in the different tests were entirely arbitrary. The lowest pressure used was that due to the head of water in the pipes and charging bucket. The higher pressures were chosen to give a convenient range as far as the nature of the different materials would permit.

1. This is a biotite granite from the Colorado Canyon, Nevada side. It has a large percentage of quartz which is interspersed with fine flakes of mica.

Physical properties:

Water absorption (by weight) .... per cent..	0. 3
Ratio a/p	1. 07
Apparent specific gravity	2. 65
Compressive strength .... lbs./in.^{2}..	22, 000

Due to the density of this material, the rate of penetration was very slow, and the time between measurement was from two to three hours for all except the low pressure, which was continued for 17 hours.

2. The specimen was a dense dioritic granite from the Colorado Canyon, Nevada side.

Physical properties:

Water absorption (by weight) per cent	0. 3
Apparent specific gravity	2. 77
Compressive strength lbs./in.^{2}	28, 000

The very slow rate of penetration and the slight increase from 1.2 to 125 pounds renders the results rather uncertain as individual values, but all testify to the fact that the material is only slightly permeable.

3. A volcanic breccia from the Colorado Canyon, Arizona side. This material consists of angular fragments from an inch in size to very small pieces firmly embedded in a fine matrix.

Physical properties:

Water absorption (by weight) per cent	2. 6
Apparent specific gravity	2. 46
Compressive strength lbs./in.^{2}	14, 000

Considering the proportionally large absorption of this material as compared with the granites, a higher rate of penetration might be expected.

4. This is a mica slate from Granville, N. Y., of green color and fine crystalline texture, containing a high percentage of quartz.

Physical properties:

Absorption (by weight) per cent	0. 2
Ratio a/p	1. 82
Apparent specific gravity	2. 76
Modulus of rupture lbs./in.^{2}	11, 000

The results indicate that this is the most nearly impermeable material tested.

5. A dark-colored mica slate from Pen Argyl, Pa., containing a rather high percentage of calcareous material.

Physical properties:

Absorption (by weight) per cent	0. 47
Apparent specific gravity	2. 78
Modulus of rupture lbs./in.^{2}	8, 000

The values obtained for this material compare very well with those obtained for the other sample of slate.

6. A fine-grained, dense calcite marble from Gantts Quarry, Ala. This specimen was prepared so that the penetration was parallel to the natural bedding of the material. It was pure white and free from veining effects.

Physical properties:

Absorption (by weight) per cent	0. 08
Ratio a/p	. 07
Apparent specific gravity	2. 72
Compressive strength lbs./in.^{2}	14, 000

At the low pressure this material appeared to be of the same order of permeability as granite but considerably higher under greater pressures.

7. This specimen was prepared from the same piece of marble as that for test No. 6, but included a few green schistlike veins. The object of this test was to determine if the veined portion was more permeable. The results indicate somewhat lower values than the entirely white portion.

8. A slightly buff, dolomitic marble from Cockeysville, Md. The specimen was of uniform composition and medium texture.

Physical properties:

Absorption (by weight) ---- per cent--	0. 10
Ratio *a/p* ----	. 005
Apparent specific gravity ----	2. 86
Compressive strength ---- lbs./in.^{2}--	22, 000

The four determinations on this indicate approximately a straight-line variation of the permeability with the pressure.

9. This test was made on a specimen of the same material as No. 8, which was treated with two coats of 45° C. melting point paraffin dissolved in benzol. The strength of the solution was approximately 10 per cent by weight. The results indicate that the treatment reduced the permeability approximately 81 per cent at the low pressure and 99 per cent at 150 lbs./in.^{2}

10. This is a coarse-grained calcite marble from Ball Ground, Ga. The specimen was of uniform composition and texture.

Physical properties:

Absorption (by weight) ---- per cent--	0. 10
Ratio *a/p* ----	. 004
Apparent specific gravity ----	2. 72
Compressive strength ---- lbs./in.^{2}--	10, 000

In this test there appears to be an inconsistency, since there was very little increase in permeability indicated from 100 to 200 pounds.

11. A test on the same marble as No. 10 treated with two coats of a 10 per cent solution of 45° C. melting point paraffin dissolved in benzol. The waterproofing result was very good, since all tests indicate a reduction of permeability of more than 98 per cent.

12. A very fine-grained, compact, dolomitic limestone from Joliet, Ill.

Physical properties:

Absorption (by weight) ---- per cent--	2. 0
Ratio *a/p* ----	2. 1
Apparent specific gravity ----	2. 63
Compressive strength ---- lbs./in.^{2}--	22, 000

It is worthy of note that the permeability of this limestone is less at the higher pressures than two of the marbles and practically the same as the least permeable one.

13. This is a light-colored oolitic limestone of uniform texture from Russelville, Ala.

Physical properties:

Absorption (by weight) ... per cent	4. 9
Ratio a/p	. 31
Apparent specific gravity	2. 34
Compressive strength ... lbs./in.^{2}	7, 300

The results approximate a straight-line variation of the permeability with the pressure. This limestone has a very low resistance to frost action, and hence it is a matter of interest to compare the permeability and other physical properties of this with the same values of other materials which are more resistant. The permeability of this material is less than the marble used in test No. 10, yet the absorption of the marble is only one-fiftieth of that of the limestone. This seems to be a logical explanation of the poor frost resistance of this limestone; that is, a high absorption and relatively low permeability. An analogy of common occurrence is the freezing of a bottle of milk in winter. The stopper offers little resistance to the expansion when freezing occurs so the frozen milk forces its way out and stands an inch or more above the top of the bottle. On the other hand, if a water pipe with closed valves freezes the pipe is sure to burst.

14. A bluish-gray, fine-grained dolomite from Mantorville, Minn. This limestone has frequent large pores and occasionally cavities an inch or more in size. The specimen was prepared to include only the material which was practically free from these large void spaces.

Physical properties:

Absorption (by weight) ... per cent	4. 5
Ratio a/p	. 28
Apparent specific gravity	2. 40
Compressive strength ... lbs./in.^{2}	12, 000

The tests indicated that some of the larger pores conducted water very freely, and three specimens were tried before one was found which was free from large continuous pores.

15. This is a yellow arenaceous dolomite from Kasota, Minn.

Physical properties:

Absorption (by weight) ... per cent	3. 2
Ratio a/p	. 37
Apparent specific gravity	2. 53
Compressive strength ... lbs./in.^{2}	20, 000

The specimen was prepared so as to indicate the permeability perpendicular to the direction of the bedding.

16. A dolomite limestone from the same locality as that used in test No. 15 and differing from it mainly in color. This was of the pink variety.

Physical properties:

Absorption (by weight)	per cent	3. 3
Ratio a/p		. 03
Apparent specific gravity		2. 53
Compressive strength	lbs./in.^{2}	20, 000

The specimen was prepared so as to indicate the permeability parallel to the bedding.

17. This was a specimen of medium-texture Indiana limestone from the vicinity of Bedford.

Physical properties:

Absorption (by weight)	per cent	4. 1
Ratio a/p		. 002
Apparent specific gravity		2. 34
Compressive strength	lbs./in.^{2}	7, 000

Measurements were made at several pressures to determine the law of variation. Figure 5 shows the curve obtained which is approximately a straight line.

18. A specimen of the same limestone used in test No. 17. The piece was made just twice as thick as the former in order to indicate the variation in permeability with the thickness. The results indicate that by doubling the thickness the permeability is reduced by about one-third.

19. A very fine-grained compact sandstone from McDermott, Ohio.

Physical properties:

Absorption (by weight)	per cent	6. 5
Ratio a/p		. 03
Apparent specific gravity		2. 21
Compressive strength	lbs./in.^{2}	9, 000

Measurements were made at several pressures in order to determine the law of variation. The results are shown in Figure 5. With the exception of the determinations at the lower pressures the variation approximates a straight line. Further discussion of this test is made in the section relating to the general discussion of results.

20. This was a sample of medium-texture sandstone from Amherst, Ohio. This sandstone consists mainly of a compacted sand which is relatively free from cementing material.

Physical properties:

Absorption (by weight)	per cent	6. 5
Apparent specific gravity		2. 16
Compressive strength	lbs./in.^{2}	8, 000

The specimen was prepared to indicate the permeability perpendicular to the bedding. The flow was so rapid that no saitsfactory measurements could be made under pressures greater than 25 pounds. This was by far the most permeable material experimented with in this group. This stone has been extensively used in building construction for many years and has shown unusually good weathering qualities. It also indicates a high degree of resistance to frost action in the laboratory tests, which fact adds to the evidence previously obtained that a durable stone must have a permeability commensurate with its absorption.

VII. DISCUSSION OF RESULTS

The actual permeability under high pressures seldom comes into consideration in the use of stone. When stone is used in high dams of the arch type, which design permits the use of relatively thin walls, the question of actual water penetration may be an important one. With this in view, some attention was given to determining the relation between the permeabilities of thick and thin specimens. Test No. 18 in the "table of results" gives values obtained on a specimen of limestone three-fourths inch thick, and test No. 19 gives the values for the same material prepared into a specimen three-eighths inch thick. A comparison of the determinations indicates that by doubling the thickness of stone the permeability is reduced by approximately one-third. This ratio is based on a limited number of determinations and should not be given too much weight, but it is believed to be of some value in the absence of other data on the subject.

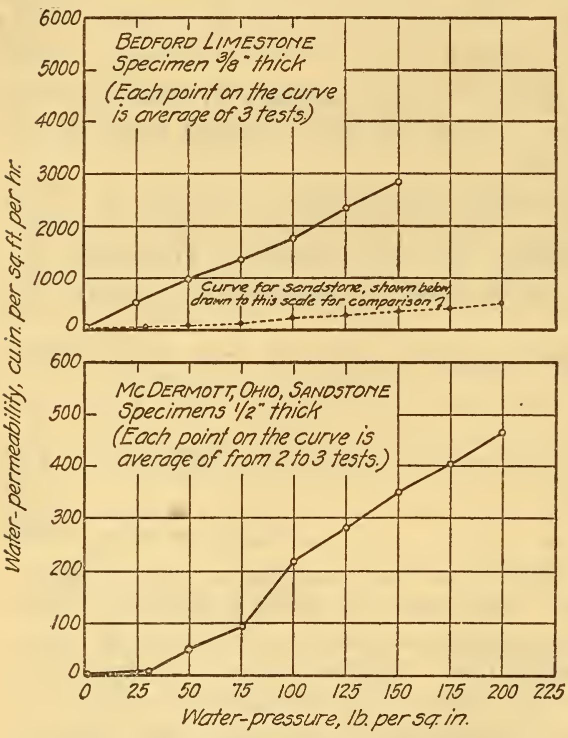


Fig. 5.—*Variation of permeability with the pressure*

The main reason for determining the permeability under pressure is to secure values which are of greater magnitude. This enables one to secure measureable quantities in a shorter period of time, but, since the values of most interest are those for low pressures, it becomes necessary to determine the law of variation of water flow under different pressures. While measurements were made on a number of specimens for three or more pressures only two were determined for a sufficient number of pressures to justify the plotting of curves. Tests 18 and 19 were made for several pressures and the curves for these are shown in Figure 5. The test on Indiana limestone indicates a linear variation. That part of the curve for the sandstone which deals with the higher pressures also indicates the same variation, but the first part indicates a retarded flow. This is believed to be due to the fact that in the first few measurements all of the pores had not come into action, and the values obtained were only for the larger pores. This is a very fine-grained, dense stone, and it seems probable that the finer pores would be slow in becoming filled. There is evidence of this in some tests which were repeated a number of times at the same pressure. The values increased for a time after the water started to flow, then after reaching a maximum there was a slight decrease in the rate. A test on limestone repeated for 30-minute intervals at the same pressure gave the following results:

	cc
First 30 minutes	5. 0
Second 30 minutes	5. 2
Third 30 minutes	5. 7
Fourth 30 minutes	5. 6

These figures indicate an increase in the rate up to one and one-half hours, after which a slight drop was noted. The decrease in rate is probably due to stopping of the pores either with loose particles of the stone or with suspended particles of solid matter or organisms in the water. On this account it appears desirable to use distilled or filtered water in making such tests when more precision is required. However, when the natural variation in the stone is taken into account it is doubtful if this would be justified if it is only desired to compare the permeability values of different materials.

Since there appears to be an increase in the rate of flow of water through a material for several minutes after the test is started, it seems advisable to adopt a standard procedure governing the time of measurements. No attempt was made in this study to determine the variations in permeability with the time for all the materials. It seems likely that the denser materials like granite and slate would show an increase in permeability over a longer period than the more porous materials due to the fact that the minute pores would become filled very slowly.

VIII. SUGGESTIONS FOR ADAPTING THE APPARATUS TO VARIOUS MATERIALS

In designing this apparatus one objective was to eliminate some of the uncertainties which exist in other types due to the use of gaskets. The scheme devised for calking the specimen into a suitable holder and then measuring the flow through a definite area at the center appears to attain this object satisfactorily for use on several types of material. However a slight modification of the means for determining the amount of water in case of some materials is necessary. The densest materials allow such a small amount to pass through that it can be absorbed in a desiccant placed near the specimen in the measuring cup. Somewhat less dense materials are too permeable to permit all the moisture to be absorbed in this way, but still the amount may be too small to measure by volumetric means. For such materials a drying system can be attached to the measuring cup by making two vents for tube connections. Such a system is frequently used in various laboratory processes and consists of a means for drawing a stream of air, first through a desiccant to dry the air, then through the chamber or material of unknown moisture content, and finally through a series of tubes containing a desiccant. The latter series of tubes is so arranged that it can be readily removed and weighed to determine the increase or amount of moisture in question.

Some of the tests made with this apparatus on thin pieces of slate and some dense marbles were found unsatisfactory because the means used did not absorb all the moisture. The drying system described above is suggested for use on such materials. With this addition and the use of the scheme previously suggested for very porous materials the apparatus can be used satisfactorily on the entire range of textures found in natural stone or similar materials.

Due to the need of a satisfactory means for testing the permeability of concrete, brick, terra cotta, etc., and the effect of waterproofings, some thought has been given to the use of this type of apparatus on such materials. Since the range in textures covered by the experiments reported herein corresponds very well with the usual range in artificial materials, it seems likely that the apparatus can be readily adapted for any of these. However, for some materials it may be desirable to enlarge the dimensions of the specimen holder in order to use larger specimens. For use on concretes with various aggregates a specimen holder has been constructed at this bureau. This utilizes a specimen 6 inches in diameter, which can be made in various thicknesses up to 2 inches.

IX. APPLICATION OF RESULTS

Absorption and porosity determinations are frequently made on stone and are considered of importance in connection with other laboratory tests. Permeability determinations are believed to afford information of value in connection with many of the uses of stone. In the case of a stone wall in a building the amount of moisture which can pass through to the interior is of more immediate importance than the amount the wall will absorb. Several problems in connection with masonry structures are concerned more or less directly with permeability, and hence a brief discussion of these problems may be justified.

1. Efflorescence on masonry is in most cases caused by water leaching through, dissolving water-soluble constituents and carrying them to the surface where they crystallize, with many ill effects. Due to the fact that a portion of the crystallization takes place in the pores of the stone near the surface, an action similar to that of frost occurs. This action is so severe that disintegration of the stonework frequently results. The leaching water may originate from rains or thawing snow which percolates downward through the coping, cornice, sills, etc., or it may proceed upward from the ground by means of capillarity, in which case it shows its effects on a few courses of stone above grade. Frequently a denser stone is used below grade and carried somewhat above grade to overcome this trouble. It appears that efflorescence could be overcome almost entirely by using dense stones in the coping and other parts where water readily finds its way into the walls.

2. Weathering of stone is usually considered to be due to frost action or the chemical action of the elements. If water did not find admittance to the interior of the stone the effect of freezing temperatures would be almost negligible. An examination of old stone buildings will usually show the greatest weathering effect where water has had the best chance to penetrate. Projecting courses of porous stone as, for instance, the cornice and coping, take up water which soaks downward through several courses of stone below. Such parts of a building suffer severely, not alone from frost action but also from the more severe disintegration effects of efflorescence.

Bridge piers of porous stone standing in water are subjected to severe weathering for several courses above the water line, due to the fact that moisture is continually creeping upward by capillarity. Probably the best way to avoid such a condition would be to use a few courses of dense material from the low-water level to slightly above the high-water level.

3. In studying the weather-resisting qualities of stone it is probably more important to determine the nature of the pores than the actual amount of pore space. It has long been the hope of investigators working along the line of weather-resisting qualities of stone to discover some simple but reliable means which can be used to determine the difference between a stone of enduring properties and one of poor quality. Actual weathering tests are expensive and few laboratories are equipped for making them. It has been suggested that a study of permeability might lead to a better understanding of the structure which determines the weathering qualities. This idea has probably never been given a fair test, but evidence exists in some of the permeability results herein that the ratio between the total absorption of a stone and its permeability may have some significance

in this respect. The ratio between the absorption value and the permeability at 100 lbs./in.^{2} has been computed for several materials and included with the other physical data in Section V. An examination of these values for comparison with the available data on weathering qualities indicates that no definite limit for this ratio could be established which would apply to all types of stone. For instance, the ratio is relatively high for granite and slate, which materials are the most resistant to weathering. However, on comparison of the ratios for materials of similar properties, as Nos. 10, 13, 14, 17, and 19, it will be seen that the second two of these show relatively high ratios while the others are low. The resistance of materials Nos. 13 and 14 to frost action has been found to be low, while that for the other three is high. The resistance of samples Nos. 12 and 15 has not been established, but the high strengths of these materials would be in favor of greater resistance.

4. Waterproofing is frequently resorted to as a means of preventing dampness and also as a means of overcoming frost action, discoloration, etc. Numerous materials have come on the market and are extensively sold for the purposes mentioned. Little information is available concerning the relative merits of different types of surface applications, and such materials are usually purchased on the recommendation of the producer. There is an urgent need for more information on the merits of such products. Evidently the real test of any waterproofing is its effect in permanently sealing the pores.

X. CONCLUSIONS

1. The apparatus described has been experimented with upon a range of materials varying from very dense to very porous and found to give satisfactory results.

2. Tests have been made on specimens of six types of natural stone which serve to indicate the relative permeability of these types.

3. A limited amount of work was done in determining the value of a penetrating waterproofing material on marble which indicated that the permeability can be reduced 98 per cent by this means.

4. The tests, in general, indicate that the relation of permeability to the pressure is approximately a straight-line ratio.

5. A limited number of tests were made to compare the permeability of specimens of different thicknesses. These indicated that by doubling the thickness the permeability was reduced by approximately one-third.

6. A discussion is made of the applicability of permeability tests to certain problems arising from the use of stone under various conditions.

WASHINGTON, July 29, 1925.